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Isolated Left Ventricular Noncompaction as a Cause for Heart Failure and Heart Transplantation: A Single Center Experience

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Key Words
Left ventricular noncompaction · Heart failure · Heart transplantation

Abstract
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Introduction

Heart failure, a common cause of hospitalization and death, is a worldwide growing public health problem due to aging of the population, improved therapy and prolonged survival after cardiac events [1]. The lifetime likelihood of developing heart failure is approximately 20% at all ages above 40 years [2, 3]. The most common etiology of heart failure remains coronary artery disease (CAD); other frequent causes include hypertension, valvular heart disease and diabetes [1, 4–7]. Isolated left ventricular noncompaction (IVNC) seems to be a rare cause of heart failure. IVNC has only become widely known in the last 10 years [8–10]. According to the new American Heart Association classification of the cardiomyopathies, IVNC is classified as a primary, genetic cardiomyopathy [11]; in the position statement of the European Society of Cardiology it is not yet classified as a distinct cardiomyopathy [12]. In symptomatic patients with IVNC, heart

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Table 1. Etiologies of heart failure

	All patients	Men (n = 788)	Women (n = 172)	p value
CAD	359 (37)	326 (41)	33 (19)	<0.0001
Dilated cardiomyopathy	319 (33)	266 (34)	53 (31)	0.48
Valvular heart disease	104 (11)	77 (10)	27 (16)	0.03
Congenital heart disease	49 (5)	31 (4)	18 (11)	0.002
IVNC	26 (3)	19 (2)	7 (4)	0.30
Hypertensive heart disease	26 (3)	17 (2)	9 (5)	0.04
Hypertrophic cardiomyopathy	15 (2)	13 (1.6)	2 (1)	1.0
Myocarditis	11 (1)	8 (1)	3 (1.5)	0.43
Amyloid heart disease	9 (0.9)	5 (0.6)	4 (2.0)	0.06
Arrhythmogenic right ventricular cardiomyopathy	9 (0.9)	7 (0.9)	2 (1)	0.67
Idiopathic restrictive cardiomyopathy	8 (0.8)	3 (0.4)	5 (3)	0.006
Neuromuscular disease	7 (0.7)	6 (0.8)	1 (0.5)	1.0
Unknown	7 (0.7)	5 (0.6)	2 (1)	0.62
Other	11 (1)	5 (0.6)	6 (4)	0.006

Figures in parentheses are percentage.

failure is common occurring in 34% and heart transplantation has been reported to be necessary in up to 14% [13]. However, the true prevalence of IVNC as a cause of heart failure and heart transplantation is unknown. In a recent study by Kohli et al. [14], involving 199 patients from a heart failure clinic, 23.6% fulfilled one or more published echocardiographic criteria for IVNC.

The goal of the present study was to evaluate the prevalence of IVNC as a cause of heart failure and heart transplantation in our center where since 1986 all patients have been routinely screened for IVNC by echocardiography.

Methods

We performed a retrospective analysis of our heart failure clinic database which was started in 1987. There were 960 patients in this database from January 1987 to December 2005, who were evaluated with a complete history, physical exam and echocardiography at our hospital. This constituted the study population. Retrospectively, all charts and echocardiography reports were reviewed.

Echocardiography

Complete two-dimensional and Doppler echocardiography was performed in all patients according to the published guidelines [15].

Since 1985, our group has been familiar with the diagnosis of IVNC and has been especially interested in its occurrence screening all patients [8]. The echocardiographic criteria for diagnosis of IVNC which were previously described by Jenni et al. [10, 16] were used. They include absence of coexisting cardiac abnormalities; segmental thickening of the left ventricular myocardial wall consisting of two layers: a thin compacted epicardial layer and a thickened endocardial layer with prominent trabeculations, and deep recesses with color Doppler evidence of blood flow from the left ventricular cavity to the deep intertrabecular recesses. A thickness ratio of noncompacted to compacted myocardium $\geq$2:1 at end systole is considered to be diagnostic of IVNC. Predominant localization of the pathology is in the apical midlateral and midinferior regions of the left ventricle and most of the noncompacted segments are hypokinetic.

Statistical Analysis

Results are presented as mean values $\pm$ standard deviation or frequency expressed as a percentage for dichotomous or qualitative variables. Nonparametric tests including Mann-Whitney U test as well as Fisher's exact test were used where appropriate. $p < 0.05$ was considered statistically significant.

Results

There were 788 men (82%). Average age at echocardiography was 52 $\pm$ 14 years overall (range 6–88), 51 $\pm$ 16 years in women (range 11–84) and 52 $\pm$ 13 years in men (range 6–88; p = 0.24). The main etiologies of heart failure are shown in table 1. The diagnostic criteria for IVNC were fulfilled in 26 patients (3%).

Heart transplantation was performed in 253 patients (26%): in 214 men (85%) and 39 women (15%). Average age at transplantation was 48 $\pm$ 12 years (range 6–66): 45

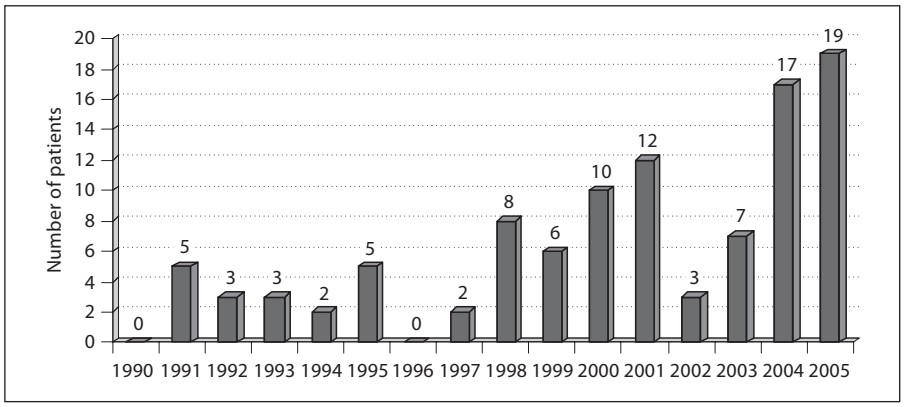

Fig. 1. Prevalence of diagnosis of IVNC in the echocardiography laboratory from 1990 to 2005. The number of patients with IVNC seen in the echocardiography laboratory in the individual years is shown. The total number of patients per year was 4,051 patients in 1990 increasing to 4,871 patients in 2005.

± 14 years in women (range 12–61) and 48 ± 12 years in men (range 6–66; p = 0.22). The main etiologies of heart transplantation are shown in table 2. As in the heart failure group, the most common valvular lesions in the heart transplant patients were mitral regurgitation (1.6%) and aortic stenosis (0.8%). IVNC as a cause of heart transplantation was present in 5 patients (2%) with mean age at heart transplantation of 47 ± 14 years (range 26–61). No other patients with IVNC were considered for heart transplantation but found ineligible or died on the waiting list.

The main etiology of heart failure by age at heart transplantation was also analyzed as shown in table 3. Patients were divided into three groups: 18 years of age or younger, 19–50 years of age and more than 50 years of age. The prevalence of CAD as a cause of heart transplantation increased with age. On the other hand, congenital heart disease, idiopathic restrictive cardiomyopathy and myocarditis were the most common causes of heart transplantation in the group of patients of 18 years of age or younger.

The main etiologies of heart failure analyzed by gender at heart transplantation are shown in table 4. We found no statistically significant difference between men and women with respect to all causes of heart transplantation except for CAD which was a significantly more common cause of heart transplantation in men (p = 0.01).

To analyze the impact of better image quality and increased awareness of IVNC, we were able to analyze the overall prevalence of the diagnosis of IVNC in the echocardiography laboratory (thus the total number is higher than 26 patients) between 1990 and 2005 in relative and absolute numbers as shown in figure 1. The years before 1990 were not available for detailed analysis. In 2004 and 2005, there was a significant increase in the diagnosis which cannot only be attributed to examination of relatives of patients with known IVNC (p = 0.02, Mann-Whitney test).

Table 2. Etiologies of heart transplantation in 253 patients

	Number of patients
CAD	98 (39)
Dilated cardiomyopathy	107 (42)
Valvular heart disease	13 (5)
Congenital heart disease	13 (5)
IVNC	5 (2)
Hypertensive heart disease	2 (0.8)
Hypertrophic cardiomyopathy	0
Myocarditis	3 (1)
Amyloid heart disease	3 (1)
Arrhythmogenic right ventricular cardiomyopathy	2 (0.8)
Idiopathic restrictive cardiomyopathy	3 (1)
Neuromuscular disease	2 (0.8)
Cardiomyopathy of unknown origin	2 (0.8)

Figures in parentheses are percentage.

Discussion

Our data show that IVNC strictly using the definitions by Jenni et al. [10] is a rare cause of heart failure and heart transplantation in our center compared to CAD, dilated cardiomyopathy or valvular heart disease. The prevalence of IVNC in this patient group seems comparable to that of hypertrophic cardiomyopathy.

Table 3. Etiologies of heart failure by age at heart transplantation

	Age ≤18 years (n = 12)	Age 19–50 years (n = 112)	Age >50 years (n = 129)	p value[a]
CAD	0	35 (31)	63 (48)	0.0001
Dilated cardiomyopathy	5 (42)	51 (45)	51 (40)	0.66
Valvular heart disease	0	7 (6)	6 (5)	0.88
Congenital heart disease	4 (33)	8 (7)	1 (0.8)	0.0001
IVNC	0	2 (2)	3 (2)	1.0
Hypertensive heart disease	0	0 (0)	2 (1.6)	0.55
Myocarditis	2 (17)	1 (0.9)	0	0.003
Amyloid heart disease	0	2 (2)	1 (0.8)	0.65
Arrhythmogenic right ventricular cardiomyopathy	0	2 (2)	0	0.29
Idiopathic restrictive cardiomyopathy	1 (8)	1 (0.9)	1 (0.8)	0.14
Neuromuscular disease	0	2 (2)	0	0.29
Cardiomyopathy of unknown origin	0	1 (0.9)	1 (0.8)	1.0

Figures in parentheses are percentage. [a] p value by Fisher's exact test.

Table 4. Etiologies of heart failure by gender at heart transplantation

	Male gender (n = 214)	Female gender (n = 39)	p value
CAD	90 (42)	8 (21)	0.01
Dilated cardiomyopathy	88 (41)	19 (49)	0.38
Valvular heart disease	13 (6)	0 (0)	0.23
Congenital heart disease	9 (4)	4 (10)	0.12
IVNC	4 (2)	1 (2.5)	0.57
Hypertensive heart disease	1 (0.5)	1 (2.5)	0.29
Myocarditis	2 (1)	1 (2.5)	0.40
Amyloid heart disease	1 (0.5)	2 (5)	0.06
Arrhythmogenic right ventricular cardiomyopathy	1 (0.5)	1 (2.5)	0.29
Idiopathic restrictive cardiomyopathy	1 (0.5)	2 (5)	0.06
Neuromuscular disease	2 (1)	0	1.0
Cardiomyopathy of unknown origin	2 (1)	0	1.0

Figures in parentheses are percentage.

Main Causes of Heart Failure and Heart Transplantation

The underlying cardiac diagnoses in an Italian registry of over 6,200 outpatients with heart failure included CAD in 40%, dilated cardiomyopathy in 32%, primary valvular heart disease in 32% and hypertensive heart disease in 11%; other diagnoses were more rare [17]. Among 960 patients in our study group, the frequency of CAD and dilated cardiomyopathy was almost the same as in the Italian registry (37 and 33%, respectively), whereas primary valvular heart disease and hypertensive heart disease with 11 and 3% were less common. IVNC as a cause of heart failure was as common as hypertrophic cardiomyopathy present in 2.7% of patients.

The 23rd Official Adult Heart Transplantation Report 2006 of the International Society for Heart and Lung Transplantation (ISHLT) [18] presented information on 73,000 transplanted patients. During the last 5 years, CAD was the indication for transplantation in 42% of cases, and noncoronary cardiomyopathy in 46%, whereas valvular and congenital heart disease was present in only 3 and 2% of transplanted patients, respectively. In our cohort, CAD was the underlying cardiomyopathy in 39% of patients, dilated cardiomyopathy in 42%, and valvular

and congenital heart disease in 5% of patients each. IVNC was the next most common cause of heart transplantation with 2%. Thus, our cohort was comparable to the ISHLT data – apart from the information on IVNC which was missing in the ISHLT 2006 report. In a recent study of primary cardiomyopathy in Australian children, IVNC was the third most common cardiomyopathy after dilated cardiomyopathy and hypertrophic cardiomyopathy [19]. In another single center series, IVNC was responsible for 9.5% of cardiomyopathies in children [20].

Definition of IVNC and Cardiomyopathies

The diagnosis of IVNC has become widely known after the establishment of clear-cut diagnostic criteria for echocardiography [9], and, therefore, patients are nowadays routinely screened for this diagnosis. IVNC was recently classified as a primary, genetic cardiomyopathy according to the American Heart Association [11]; in the position statement of the European Society of Cardiology, IVNC is not classified as a distinct cardiomyopathy [12].

The most widely used diagnostic criteria are the ones proposed by our group [10]. The first diagnostic criteria for IVNC were published by Chin et al. [9], defining IVNC criteria at end diastole, requiring a ratio of <0.5 which is very similar to the approach of Jenni et al. Stollberger et al. [21] proposed to use the criterion of more than three trabeculations protruding from the left ventricular wall, apically to the papillary muscles, visible in a single image plane in combination with intertrabecular spaces perfused from the left ventricular cavity.

Prevalence of IVNC in Patients

The increasing prevalence of IVNC also in the echocardiography laboratory shows that, even in our hands, IVNC might have been undetected in some patients in the past due to previous technical inadequacy of the echocardiographic machines. The results of our center are unique as all patients with heart failure have been screened for this diagnosis since 1986.

A recent study by Kohli et al. [14] suggested that at least one set of IVNC criteria may be fulfilled in up to 23.6% of 199 patients in their heart failure clinic with an increased prevalence in black patients. These authors used all 3 published criteria for IVNC: by Chin et al. [9], by Jenni et al. [10], and by Stollberger et al. [21]. The definitions by Jenni et al. were fulfilled in 30 patients, the criteria of Chin et al. in 37 patients and the criteria proposed by Stollberger et al. in 25 patients. The findings of this study do not suggest that IVNC is indeed such a common cause of heart failure, but that the proposed criteria have to be defined more strictly or to be applied more carefully. For the definitions by Jenni et al., wall thickening of the affected wall is a very important criterion and is neglected by many who try to apply the criteria. In many publications, wall thickening is not mentioned as a criterion. There is no doubt that the entity of IVNC does exist; however, as some persistence of the trabecular layer seems to be quite common, the cutoff for the extent where it is clinically significant has to be defined carefully.

In one study cohort with 45 patients, 8 of 32 screened relatives had a range of echocardiographic abnormalities including IVNC or left ventricular enlargement without IVNC, features resembling dilated cardiomyopathy with recesses [22]. This is similar to hypertrophic cardiomyopathy where definite carriers do not necessarily have all features or variable features due to variable penetrance of the phenotype, or where some definite cardiac β-myosin heavy chain defect carriers may show features resembling noncompaction [23]. This does not prove that IVNC may not present itself as a distinct cardiomyopathy but that a spectrum of abnormal maturation of the myocardium may be quite common with only the most severe forms producing a pathological entity [24].

Heart Transplantation and IVNC

Whereas the prognosis of symptomatic IVNC is poor, so far only rare cases of heart transplantation in IVNC have been described [13, 25, 26]. Pathologic examination of the explanted hearts nicely demonstrated the underlying pathology. Interestingly enough, the diagnosis was not commonly made at pathology in the past, but most pathologists became aware of the disease when it had been described at catheterization and by echocardiography. Therefore, the true prevalence of IVNC as a cause for heart transplantation if examining only the explanted hearts or in large autopsy series may be underestimated. Besides, as shown in the beautiful paper by Burke et al. [27], IVNC can be variable even at autopsy presenting as anastomosing broad trabeculae, coarse trabeculae resembling multiple papillary muscles or interlacing smaller muscle bundles resembling a sponge. This makes the diagnosis even more difficult.

Limitations

The retrospective study design and the selection bias of a tertiary care center are the major limitations. The prevalence of several etiologies of heart failure is likely to be underestimated in the heart failure clinic in our hospital as patients with HIV cardiomyopathy, chemothera-

py-induced cardiomyopathy, heart failure due to connective tissue disease or cardiomyopathy due to end-stage systemic disease (amyloid heart disease) might not be referred to the same degree as heart failure with other diagnoses.

The prevalence of the different etiologies of heart failure does not reflect the whole age spectrum as elderly patients might not be referred to the heart failure clinic as frequently as younger people.

Typically, patients seen in the heart failure clinic are symptomatic. We cannot determine the prevalence of IVNC in patients with asymptomatic left ventricular dysfunction. However, we suspect that the prevalence may even be higher than we assume, as asymptomatic patients with IVNC are increasingly detected due to the increased awareness of this cardiomyopathy [13].

Diastolic heart failure is increasingly recognized in the population defined as signs and symptoms of heart failure and preserved systolic function [28]. Isolated diastolic dysfunction is present in more than 40% of patients with heart failure [29]. However, diastolic heart failure as a specific diagnosis has not been coded as such in our database and is included in the other diagnosis groups.

Conclusion

The most common causes for heart failure and heart transplantation remain dilated cardiomyopathy, CAD and valvular heart disease. Among patients followed in our heart failure clinic, IVNC is a rare underlying cardiomyopathy for both, heart failure (2.7%) and heart transplantation (2%). However, its prevalence is comparable to hypertrophic cardiomyopathy if the diagnostic criteria are known and used correctly.

References

1 Swedberg K, Cleland J, Dargie H, et al: Guidelines for the diagnosis and treatment of chronic heart failure: executive summary (update 2005): The Task Force for the Diagnosis and Treatment of Chronic Heart Failure of the European Society of Cardiology. Eur Heart J 2005;26:1115–1140.
2 Lloyd-Jones DM, Larson MG, Leip EP, et al: Lifetime risk for developing congestive heart failure: the Framingham Heart Study. Circulation 2002;106:3068–3072.
3 American Heart Association: Heart Disease and Stroke Statistics – 2005 Update. Dallas, American Heart Association, 2005.
4 He J, Ogden LG, Bazzano LA, Vupputuri S, Loria C, Whelton PK: Risk factors for congestive heart failure in US men and women: NHANES I epidemiologic follow-up study. Arch Intern Med 2001;161:996–1002.
5 Kannel WB, Ho K, Thom T: Changing epidemiological features of cardiac failure. Br Heart J 1994;72(2 suppl):S3–S9.
6 Gheorghiade M, Bonow RO: Chronic heart failure in the United States: a manifestation of coronary artery disease. Circulation 1998; 97:282–289.
7 Hunt SA, Abraham WT, Chin MH, et al: ACC/AHA 2005 Guideline Update for the Diagnosis and Management of Chronic Heart Failure in the Adult: a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines (Writing Committee to Update the 2001 Guidelines for the Evaluation and Management of Heart Failure): developed in collaboration with the American College of Chest Physicians and the International Society for Heart and Lung Transplantation: endorsed by the Heart Rhythm Society. Circulation 2005;112:e154–e235.
8 Jenni R, Goebel N, Tartini R, Schneider J, Arbenz U, Oelz O: Persisting myocardial sinusoids of both ventricles as an isolated anomaly: echocardiographic, angiographic, and pathologic anatomical findings. Cardiovasc Intervent Radiol 1986;9:127–131.
9 Chin TK, Perloff JK, Williams RG, Jue K, Mohrmann R: Isolated noncompaction of left ventricular myocardium. A study of eight cases. Circulation 1990;82:507–513.
10 Jenni R, Oechslin E, Schneider J, Attenhofer Jost C, Kaufmann PA: Echocardiographic and pathoanatomical characteristics of isolated left ventricular non-compaction: a step towards classification as a distinct cardiomyopathy. Heart 2001;86:666–671.
11 Maron BJ, Towbin JA, Thiene G, et al: Contemporary definitions and classification of the cardiomyopathies: an American Heart Association Scientific Statement from the Council on Clinical Cardiology, Heart Failure and Transplantation Committee; Quality of Care and Outcomes Research and Functional Genomics and Translational Biology Interdisciplinary Working Groups; and Council on Epidemiology and Prevention. Circulation 2006;113:1807–1816.
12 Elliott P, Andersson B, Arbustini E, et al: Classification of the cardiomyopathies: a position statement from the European Society of Cardiology Working Group on Myocardial and Pericardial Diseases. Eur Heart J 2008;29:270–276.
13 Lofiego C, Biagini E, Pasquale F, et al: Wide spectrum of presentation and variable outcomes of isolated left ventricular noncompaction. Heart 2007;93:65–71.
14 Kohli SK, Pantazis AA, Shah JS, et al: Diagnosis of left-ventricular non-compaction in patients with left-ventricular systolic dysfunction: time for a reappraisal of diagnostic criteria? Eur Heart J 2008;29:89–95.
15 Schiller NB, Shah PM, Crawford M, et al: Recommendations for quantitation of the left ventricle by two-dimensional echocardiography. American Society of Echocardiography Committee on Standards, Subcommittee on Quantitation of Two-Dimensional Echocardiograms. J Am Soc Echocardiogr 1989;2:358–367.
16 Jenni R, Oechslin EN, van der Loo B: Isolated ventricular non-compaction of the myocardium in adults. Heart 2007;93:11–15.
17 Baldasseroni S, Opasich C, Gorini M, et al: Left bundle-branch block is associated with increased 1-year sudden and total mortality rate in 5517 outpatients with congestive heart failure: a report from the Italian network on congestive heart failure. Am Heart J 2002;143:398–405.
18 Taylor DO, Edwards LB, Boucek MM, et al: Registry of the International Society for Heart and Lung Transplantation: twenty-third official adult heart transplantation report – 2006. J Heart Lung Transplant 2006;25:869–879.

19 Nugent AW, Daubeney PE, Chondros P, et al: The epidemiology of childhood cardiomyopathy in Australia. N Engl J Med 2003;348:1639–1646.
20 Pignatelli RH, McMahon CJ, Dreyer WJ, et al: Clinical characterization of left ventricular noncompaction in children: a relatively common form of cardiomyopathy. Circulation 2003;108:2672–2678.
21 Stollberger C, Finsterer J, Blazek G: Left ventricular hypertrabeculation/noncompaction and association with additional cardiac abnormalities and neuromuscular disorders. Am J Cardiol 2002;90:899–902.
22 Murphy RT, Thaman R, Blanes JG, et al: Natural history and familial characteristics of isolated left ventricular non-compaction. Eur Heart J 2005;26:187–192.
23 Hoedemaekers YM, Caliskan K, Majoor-Krakauer D, et al: Cardiac beta-myosin heavy chain defects in two families with non-compaction cardiomyopathy: linking non-compaction to hypertrophic, restrictive, and dilated cardiomyopathies. Eur Heart J 2007;28:2732–2737.
24 Anderson RH: Ventricular non-compaction – a frequently ignored finding? Eur Heart J 2008;29:10–11.
25 Stamou SC, Lefrak EA, Athari FC, Burton NA, Massimiano PS: Heart transplantation in a patient with isolated noncompaction of the left ventricular myocardium. Ann Thorac Surg 2004;77:1806–1808.
26 Oechslin EN, Attenhofer Jost CH, Rojas JR, Kaufmann PA, Jenni R: Long-term follow-up of 34 adults with isolated left ventricular noncompaction: a distinct cardiomyopathy with poor prognosis. J Am Coll Cardiol 2000;36:493–500.
27 Burke A, Mont E, Kutys R, Virmani R: Left ventricular noncompaction: a pathological study of 14 cases. Hum Pathol 2005;36:403–411.
28 Chinnaiyan KM, Alexander D, Maddens M, McCullough PA: Curriculum in cardiology: integrated diagnosis and management of diastolic heart failure. Am Heart J 2007;153:189–200.
29 Bursi F, Weston SA, Redfield MM, et al: Systolic and diastolic heart failure in the community. JAMA 2006;296:2209–2216.